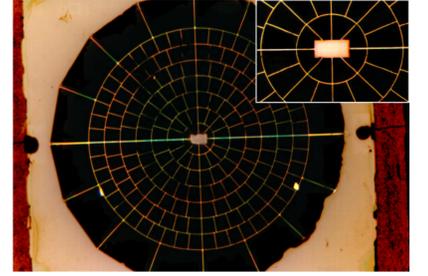


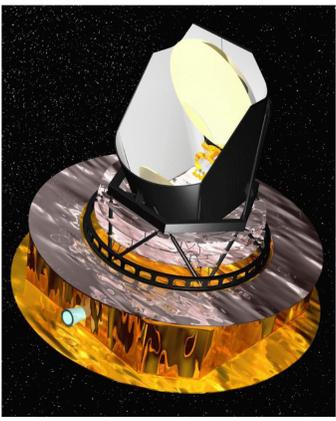
Use of High Sensitivity Bolometers on Planck High Frequency Instrument

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View of a Caltech/ JPL spider web bolometer (from J.J. Bock et al. [1, 2, 3])

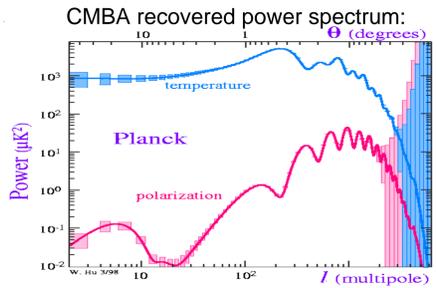


Planck scientific objectives

- Dedicated to survey the sky at sub-mm and mm wavelength
- Primary scientific goal: **Cosmic Microwave Background Anisotropies**
 - $T/T \sim 2.10^{-6}$
 - 5 arcmin resolution
 - about 1000 times more sensitive than COBE-DMR

Onboard Planck:

- Low Frequency Instrument (LFI): Radiometers
- High Frequency Instrument (HFI) [4]:
 - 48 bolometers at 100mK
 - 6 bands between 300 μ m and 3mm
 - Polarisation measurement in 3 channels



Comparison with theoretical models allow to deduce cosmological parameters at 1% accuracy.

Wavelength ranges

Measurement of CMBA and each background components that « contaminate » the CMBA [5]:

(Galactic free-free and synchrotron emission covered by LFI)

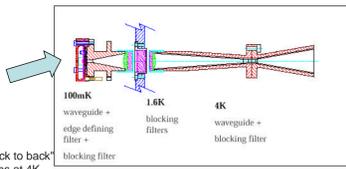
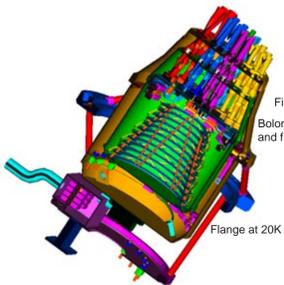
- CMBA (Common with LFI)
- Negative Sunyaev Zeldovic effect
- CMBA
- Positive Sunyaev Zeldovic effect
- Dust and galaxies
- Dust and galaxies

Central Frequency (v)	Ghz	100	143	217	353	545	857
Central wavelength	mm	3.0	2.1	1.38	0.85	0.55	0.35
Bandwidth	$\lambda/d\lambda$	3	3	3	3	3	3

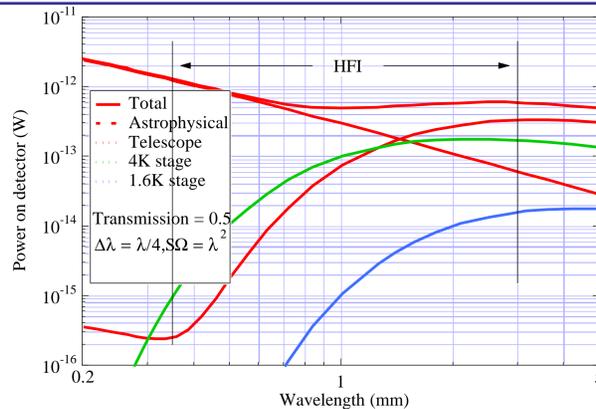
The absorber of the bolometer must be larger than the wavelength ($\sim 1.5l$ or $2l$)

Background loads / NEPs

- Background power:
 - Telescope at about 50K
 - HFI optical chain:



Use of active cooler
 18K: H₂ J-T Sorption pumps (JPL, USA)
 4K: He J-T Mech. Pump (RAL, UK)
 0.1K and 1.6K: ³He/⁴He dilution and J-T expansion (AL, CRTBT, IAS, France)



Background power dominated by CMB at low frequency and by the telescope at high frequency, which gives the photon noise [4, 6].

Central Frequency (v)	Ghz	100	143	217	353	545	857
Optical load (2 polars)	pW	1.0	1.1	1.1	1.0	5.0	16.
Optical load (polarised)	pW	-	0.71	0.54	0.50	-	-

Drives the NEP requirement:

$$NEP_{DARK} = NEP_{photon}$$

Central Frequency (v)	Ghz	100	143	217	353	545	857
NEP (unpolarised)	$10^{-17} \text{WHz}^{-1/2}$	1.2	1.5	1.8	2.2	6.0	14.
NEP (polarised)	$10^{-17} \text{WHz}^{-1/2}$	-	1.2	1.3	1.5	-	-

The only way to do better at low frequency is to increase the number of detectors

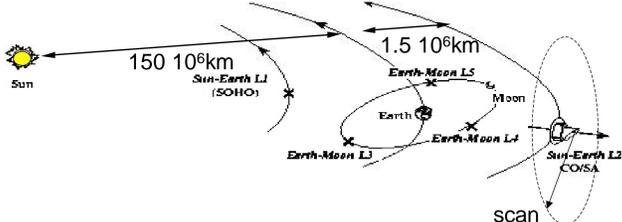
- HFI:
 - Unpolarised channels: 4 bolometers
 - Polarised channels: 8 bolometers with 4 polarisation angles

Time response

Depends on signal frequency content.

Scanning strategy:

- Halo orbit around L2
- Rotation at 1 RPM
- Telescope axis at 85deg from spin axis
- Repointing every ~ 60 min by 2.5arcmin steps



The useful signal is in audio band pass:

- From 1/60 Hz (transmit all components)
 - DC components are given up (not re-do COBE)
 - DC data be recovered in map making
- To ~ 100 Hz (transmit 5' beams)

⇒ Need of low frequency stability

- AC readout electronics based on a capacitive biasing of the bolometer [7, 8]

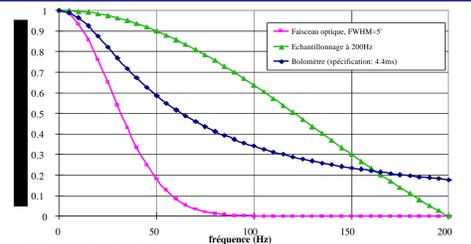
⇒ Drives the detector chain transfer function

⇒ Drives the detector layout

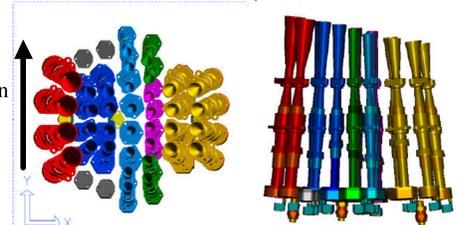
Central Frequency (v)	Ghz	100	143	217	353	545	857
Angular resolution	arcmin	9.2	7.1	5.0	5.0	5.0	5.0
Required time constant	ms	7.8	5.7	4.4	4.4	4.4	4.4
Goal time constant	ms	3.9	2.9	2.2	2.2	2.2	2.2

Filtering effect of:

- Readout
- Bolometer
- Beam



Scan direction



Temperature

- Modelling of bolometer performance (J. Bock, J.P. Torre, J.M. Lamarre):

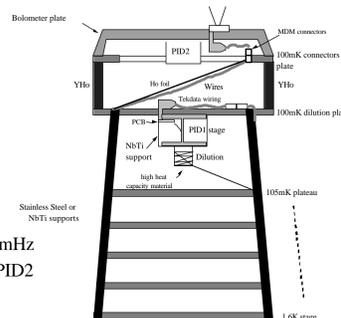
Required temperature for spider web bolometers: $T_0 = 100\text{mK}$

Practice: Time constant is the most demanding parameter

Temperature fluctuations of the optical chain are seen as a signal [9].

- Temperature fluctuations between 0.016Hz and 100Hz must be less than:
 - 20 nK Hz^{-1/2} on the 100mK stage
 - 28 μ K Hz^{-1/2} on the 1.6K stage
 - 10 μ K Hz^{-1/2} on the 4K stage
- Long term stability (15 days) of the 100mK must be better than 0.5mK for proper response stability of the bolometers

100mK stage thermal architecture:



- Sources of fluctuations
 - Dilution
 - Thermal loading on the bolometer plate
- Low pass filter: HoY alloy
 - $f_{cut} \sim 1\text{mHz}$
 - Damping > 100 for $f > 16\text{mHz}$
- Thermal control PID1 and PID2

High sensitivity Ge NTD thermometers have been developed to measure such low temperature fluctuations [10, 11]:

- Measured sensitivity of < 10nK.Hz^{0.5} down to 0.1Hz
- Limited by test setup at lower frequencies

Expected sensitivity at map level

Table 2: Best expected mean properties of maps obtained with Planck-HFI

Central Frequency (v)	Ghz	100	143	217	353	545	857
Spectral resolution	$\sigma/\Delta\nu$	3	3	3	3	3	3
Beam Full Width Half Maximum	arcmin	9.2	7.1	5.0	5.0	5.0	5.0
DI/T Sensitivity (Intensity/pixel)	mKK	2.2	2.4	3.8	15	17	8000
DI/T Sens/pixel (U and Q) Polar.	mKK	-	4.8	7.6	30	-	-
Total Flux Sensitivity per pixel	mJy	9.0	12.6	9.4	20	46	52
γ SZ per FOV (sd°)		1.2	2.1	440	6.4	32	730

The sensitivity in this table is given in relative thermodynamic temperatures, i.e. as sensitivity to relative changes of CMB temperature. It is also given in Flux units for point sources, and in term of the comptonisation factor γ SZ for the observation of clusters of galaxies.

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